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Modelling of a Photovoltaic Array Using Analog System Lab Kit Pro Board

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Abstract—This paper discusses modelling and parameters investigation of a photovoltaic array using Analog System Lab Kit Pro board offered by Texas Instrument for instructional laboratories on Electric and Electronic Engineering. The modelling of PV array is based on representation of the current-voltage characteristic by an analogue circuit developed using the components available on the Lab Kit board. The model is applicable for instructional laboratory investigation on the array current-voltage characteristic and its performance at maximum power point. This investigation expands the portfolio of the laboratory works available through Analog System Lab Kit Pro board.

Keywords—ASLK PRO; instructional laboratory; photovoltaic; current-voltage characteristic; maximum power point

I. INTRODUCTION

Photovoltaic (PV) technologies have been intensively developed over the past decade and significantly increased its share in the electricity generation. It has been reported that due to reduction in the cost of PV array manufacturing and installation the global PV capacity achieved the value of 227.1 GW in the end of 2015 [1]. This expansion of PV technologies demands skilled specialists in the area of design, manufacturing and installation of photovoltaic applications. Since early 2000s PV technologies are incorporated into the engineering curriculum of many vocational, further and higher education providers such as technical schools, colleges and universities specialised on the delivery of STEM (Science, Technology, Engineering and Mathematics) subjects [2].

Teaching strategy for engineering based programmes demands a practical component incorporated into the learning process to underpin theoretical knowledge. These practical assignments are usually conducted in instructional laboratories using appropriate equipment. In terms of PV technologies, this requires the laboratory equipment designed to support an effective execution of the practical elements of the PV curriculum [3]-[6].

The main learning outcome of practical experiments on PV technology is the understanding of Maximum Power Point (MPP) of the photovoltaic I-V characteristic and its relation with the weather conditions. This can be achieved using PV emulators based on voltage power supplies operating under control algorithms simulating non-linearity of photovoltaic I-V characteristic [7]-[12]. However, a non-linear model of the PV array can be simulated using standard educational equipment designed for electrical and electronic engineering curriculum. Therefore, this paper discusses a PV emulator build using Analog System Lab Kit PRO offered by Texas Instruments for educational purposes.

The Analog System Lab Kit PRO (ASLK PRO) is a very popular educational hardware platform designed to execute laboratory experiments for students studying principles of analogue and digital electronics. The Lab Kit hardware is supplied with a tutorial book describing the details of 14 experiments developed to cover major components of the course curriculum on electronic engineering. These includes op-amp based analogue circuits (e.g. amplifiers, filters, and oscillators), switching mode power supplies and digital control of amplifiers and oscillators [13], [14].

However, the application area of the lab kit is not limited by these 14 laboratory experiments. The structure of the platform is open and can be used for the implementation of a large variety of practical experiments expanding the portfolio of laboratory exercises on courses related to electrical and electronic engineering. For example, [15] and [16] suggest to use Analog System Lab Kit Pro for the practical investigation of control algorithms which have been previously simulated in the Matlab/Simulink environment. The comparative analysis of the controller practical design and its Matlab simulation provides the students with understanding of relation between theoretical approaches and practical implementations. Kanmani [17] described a series of laboratory experiments designed to analyse various methods of signal modulation. The laboratory experiments utilise two analogue multipliers and one operational amplifier of the lab kit. The lab kit has

been also used to design practical circuit hardware in order to verify performance of a Digitally Controlled Oscillator integrated as a main component into a Phase-Locked Loop system [18]. A series of practical experiments have been suggested by Belega et al. [19] as part of laboratory work portfolio for the studying principles of the electrical and electronic measurements.

II. EMULATOR

The emulator is based on the circuit suggested by Schofield et al. [20] where the key component utilised to provide a non-linearity of I-V characteristic is a diode chain. The equivalent circuit of a PV-cell based on a single diode model approach is shown in Fig. 1. This model is quite simplified taking into account the assumptions that it has no shunt current and series resistor. Therefore, the equivalent circuit performance is described by the following mathematical relation:

$$I_{PV} = I_{PH} - I_S \left[\exp\left(\frac{V_{PV}}{V_T}\right) - 1 \right] \quad (1)$$

where V_{PV} is the terminal voltage of PV cell; I_{PV} is the terminal (output) current of the cell; I_{PH} is the photocurrent generated by the cell due to sun irradiance; V_T is the thermal voltage of the diode; I_S is the diode saturation current.

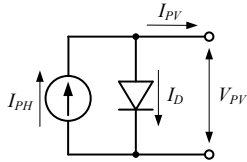


Fig. 1. Equivalent circuit of a PV-cell.

Fig. 2 shows the circuit diagram of the PV array model using the components of the Analog System Lab Kit Pro board. All component indexes in Fig. 2 are in accordance to the kit manual [14]. The photocurrent proportional to the sun

irradiance is simulated by a voltage from the potentiometer P1 operating as a voltage divider where the voltage of 10 V is corresponding to the sun irradiance of 1000 W/m² (e.g. 1 V is equivalent to 100 W/m²). A particular value of sun irradiance (from 0 to 1000 W/m²) to simulate weather condition can be installed using the potentiometer. The PV array output current I_{PV} is represented by a feedback voltage measured across the current sensor R_{SH} . The differential amplifier based on OP2.1 subtracts the feedback voltage from the potentiometer voltage and applies the result to the input of the log amplifier OP1.1 having two diodes (D1, D2) and resistor R15 in the feedback circuit. In fact, the log amplifier provides required non-linearity of I-V characteristic of the modelled PV array. The output of the log amplifier is multiplied by an inverting op-amp OP1.2. The amplifier OP2.2 and transistor cascade adjust the output of OP1.2 to the voltage scale of 30 V where V_{PV} is the terminal voltage of the PV array. The final equation describing performance of the PV array model is given below

$$V_{PV} = KnV_T \times \ln \left[\frac{I_{PH} - I_{PV} - I_R}{I_S} + 1 \right] - R_{SH} I_{PV} \quad (2)$$

where n is the number of diodes ($n = 2$); K is the gain of the amplifier OP1.2; I_R is the current through the resistor R15; R_{SH} is the current sensor.

According to [20] the shape of the I-V characteristic depends of type of the diodes, their number in the chain and the resistor connected in parallel. An additional series resistor can be also included in the diode chain to modify the I-V curve shape. The suggested PV array model is designed to provide the open circuit voltage of 30 V and the short circuit current of 300 mA under the sun irradiance condition of 1000 W/m².

III. TEST RESULTS

The PV array model is tested using an additional variable load resistor R_L connected to the out terminals of the circuit as

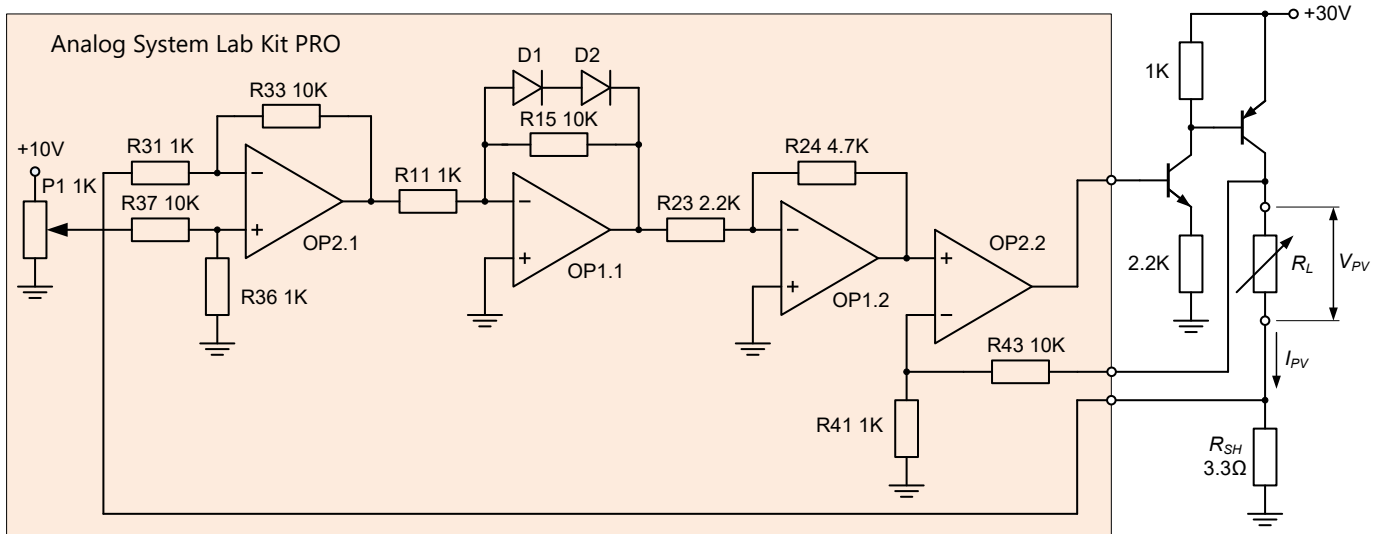


Fig. 2. Circuit diagram of the PV array model using the components of the Analog System Lab Kit Pro board.

shown in Fig. 2. In case of the automated test procedure this resistor can be replaced by an electronic controllable load device operating under a test software algorithm. The test of the model has been conducted to simulate five different values of the sun irradiation: 200 W/m², 400 W/m², 600 W/m², 800 W/m², and 1000 W/m². Hence, the potentiometer P1 has been adjusted to provide the voltage of 2 V, 4 V, 6 V, 8 V, and 10 V respectively. The family of I-V characteristics are shown in Fig. 3. Apparently, Fig. 4 demonstrates the family of power-voltage (P-V) characteristics corresponding to the Fig. 3 curves.

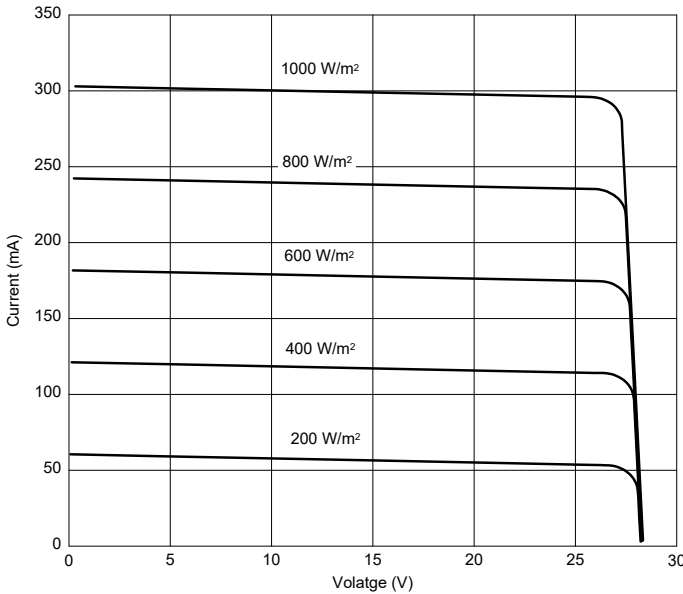


Fig. 3. Set of I-V characteristics for various sun irradiance levels.

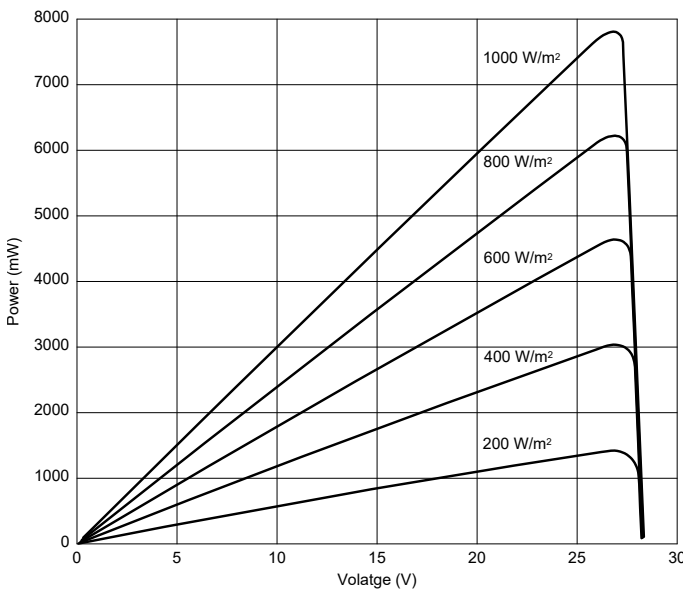


Fig. 4. Set of P-V characteristics for various sun irradiance levels.

It can be seen that the I-V curves are simplified comprising of two line mainly. Although it is quite far from realistic PV array characteristics the curves demonstrate the main features of photovoltaics – non-linearity and “knee” in the point of the

maxim power output. This is why the modelled I-V characteristics can be successfully used for study and analysis of principles of operation of PV arrays and its performance at a maximum power point.

IV. CONCLUSION

The paper discusses the Analog System Lab Kit Pro board utilised for the modelling of I-V characteristics of a PV array. The model is based on the emulator suggested by Schofield et al. [20] and applicable for instructional laboratory to investigate the main features of PV array characteristics at a maximum power point. This practical exercise can expand the portfolio of the laboratory works available through Analog System Lab Kit Pro board.

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